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Transverse (Harris) Lines in Irish Archaeological Remains

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ABSTRACT Transverse lines were examined in 633 long bones from 73 individuals exhumed from two burial sites in the Republic of Ireland: Waterford City and Tintern Abbey. The burials cover four distinct periods between the 11th and 17th centuries. Lines were most numerous in the tibia, especially in the distal segment, and were not seen in the humerus nor the proximal part of the femur. The number of lines varied between the proximal and distal segments of each long bone, and though apparently equal in number across the midline, there were significant differences in the incidence of lines between corresponding pairs of bones. Thus, it is unwise to rely on the results of a single bone or one type of long bone alone either to indicate the health status of an individual, or as the basis for assessing the health status of a small population. Such results should be used only in association with other indicators.

Transverse lines in bone (Fig. 1) were observed in a variety of clinical and experimental studies, notably rickets, in the late 19th century. However, in the 1920s, Harris was the first to examine their nature as "tombstones" to the past illness of an individual. Later studies found that when elemental phosphorus, which was then used as a treatment for rickets, was administered to patients in a solution of almond oil and later cod-liver oil, transverse lines were formed as the rickets healed (Phemister, 1921). It was subsequently concluded that the phosphorus was responsible for the formation of the transverse line, and that it was actually the oil containing vitamin D that cured the disease (Hess and Weinstock, 1926).

Subsequent clinical observations and experimental studies (Toser, 1918; Hess et al., 1921) have demonstrated that transverse lines may result from a variety of disturbances in growth, whether produced by the ingestion of substances (Caffey, 1931), dietary deficiencies (Harris, 1927a,b; Wolbach, 1947; Park and Richter, 1953; Acheson, 1959; Platt and Stewart, 1962), or illness (Acheson, 1959). Current theory suggests that transverse lines are formed in long bones when cartilage growth is interrupted in an epiphyseal plate but osteogenesis continues in the adjoining end of the diaphysis (Wolbach, 1947; Follis and Park, 1952; Park and Richer, 1953; Park, 1954, 1964; Acheson, 1959; Platt and Stewart, 1962; Woodall, 1968; Schoenboerner et al., 1982). When the epiphyseal plate begins to grow again, it does so slowly at first, so that bone deposition in the diaphysis continues to outpace longitudinal bone growth for a time, resulting in a thickening of the zone of high-density bone. In radiographs made with the axis of the bone held parallel to the film surface, the resulting disk of thickened, conjoined bony

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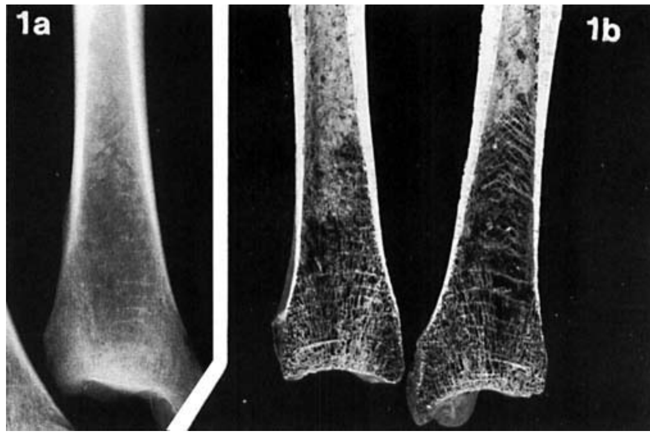


Fig. 1. Transverse lines in the distal tibia of an adult (A191) buried in Waterford in the 17th century. **a:** On radiograph. **b:** Macroscopically in section.

trabeculae casts an edge-on shadow onto the film and thus appears as a transverse line in the diaphysis.

The first systematic examination of these transverse lines in human bones was undertaken by Harris (1926, 1931a,b, 1933), who described them as "lines of cessation of growth." These pioneering studies by Harris led to the familiar eponym of "Harris lines," and showed that children suffering from many types of upper and lower respiratory infections, infectious diseases, and diabetes could develop transverse lines as a result. Children suffering from lead poisoning also appear to have Harris lines, though close inspection here indicated exaggerated trabeculae composed of lead (Caffey, 1931). Harris concluded that the most important factor in the appearance of transverse lines was the duration of growth arrest, rather than the nature of disease or other insult producing arrest. His conclusions were confirmed and added to in later years by others (Bogan and Morrison, 1927; Hewitt et al., 1955). In a study of monozygotic triplets (Sontag and Comstock, 1938), it was concluded that line formation was not hereditary, as one individual had more lines than the others even though they had identical illnesses. Line formation without evidence of past illness led Marshall (1966) to suggest that the number of lines could not be used as an indication of the number of illnesses suffered by the child. Lines were found symmetrically distributed around the skeleton, were especially numerous and conspicuous at the more rapidly growing end of each bone, and were parallel to the ends of the shafts, curving if the cartilage shaft junction curved (Eliot et al., 1927; Park, 1964). Lines sometimes exhibited deficiencies at one or more points along their length, and were thinner near the marrow cavity.

Longitudinal studies (Hewitt et al., 1955; Garn et al., 1968a,b; Gindhart, 1969) have shown that the formation of new lines in bone peaks in the second or third year of life and diminishes after the fifth year of life. New lines rarely appear in teenagers; when they do, they are usually restricted to the distal tibia. In only 25% of cases was a new line formed following documented disease or trauma, and in approximately 10% of cases new lines observed in the distal tibia were associated with neither disease nor trauma. Lines in the distal tibia were more frequent in boys, but did not persist as long as in girls. In a high proportion of patients, transverse lines were also reported to occur after the fracture of a bone (Allison et al., 1974; Ferrozzi et al., 1990).

Investigations into the effect of nutrition on line formation (Eliot and Jackson, 1933; Dreizen et al., 1956, 1964; Acheson et al., 1974) concluded that nutritional status did not, in itself, determine the susceptibility to

line formation, though it did play a role in the rapidity with which children recovered from metabolic disorders. It was suggested that in these cases the presence of lines may be due to cortical thinning allowing lines to be observed more easily (Garn and Braunstein, 1986).

Transverse lines observed in the long bones of stillborn children, and in the metaphyses of living children taken 4 weeks after birth, indicated that they can be formed prenatally (Harris, 1927a,b; Gindhart, 1969). Some lines not present at birth have been found at 1 month, suggesting that the trauma of birth was the cause, especially if the mother was in a poor state of health, overweight, or of a low economic status (Eliot et al., 1927; Sontag and Harris, 1938).

The effect of illness on individual height has provided conflicting views. On the one hand, Hewitt et al. (1955) and Acheson et al. (1974) showed that boys with Harris lines were 2.2 cm shorter than those without; girls showed similar but less striking differences. On the other hand, Garn and Schwager (1967) and Gindhart (1969) reported conflicting results. Prader et al. (1963) showed that there was a growth spurt, following growth delay due to illness or starvation, which made up the deficit. New lines have never been reported to form in mature adult bone, supporting Harris' original definition of transverse lines as "lines of cessation of growth." They do persist into adulthood and in cadavers after death (Harris, 1931a,b, 1933; Stammel, 1941). In later life they are prone to the normal processes of bone remodeling, and could disappear through this process.

The only large-scale investigation of transverse lines in living adults (Garn and Schwager, 1967) found an average incidence of 12% in adult males and 23% in females, with fewer lines in older than in younger males and females. Such persistent lines in adult bones were situated some distance from the epiphysis, suggesting formation before adolescence (Garn et al., 1968b).

The frequency and position of transverse lines in early skeletal remains have been used to provide morbidity data for ancient populations. For example, Egyptian mummies demonstrated a high frequency of lines, which were believed to indicate poor nutrition (Gray, 1967; Cockburn, 1980; Harris and Wente, 1980). However, an Australian Aboriginal skeleton 4,000–6,000 years old showed evidence of transverse lines that varied little from a modern-day control (Gill, 1968).

By measuring rises and falls in the number of lines within a population, comparisons have been made of the nutritional state of agricultural communities and those of (1) hunter gatherers and (2) maritime communities (Cook, 1979; Cassidy, 1980; Rathbun, 1981; Allison et al., 1974; Buikstra, 1976). In these studies, the randomly distributed lines visible in the agriculturists were interpreted as reflecting disease and periods of starvation due to crop failure. A lower incidence of lines was considered to be indicative of healthier populations. Younger individuals in each population had more lines than older individuals (McHenry, 1968). These findings have been extended to interpretations involving social status (Hatch, 1983).

Two principal methods have evolved to indicate the health status of the population during growth. One relies on a total count of lines and the number of lines per individual (McHenry, 1968; McHenry and Schultz, 1976; Cook, 1979; Cassidy, 1980; Clarke, 1982; Venter, 1986; Rathbun, 1987; Brennan, 1988), while the other estimates the age of formation of these natural markers (Wells, 1961, 1964a,b, 1967; Woodall, 1968; Allison et al., 1974; Hunt and Hatch, 1981; Hatch, 1983; Hummert and Van Gerven, 1984, 1985; Maat, 1984; Byres, 1991).

Wells (1961, 1967) invoked the findings of clinical studies (Digby, 1916; Bisgard and Bisgard, 1935; Anderson et al., 1963) in making the first attempt to age transverse lines in archaeological material and determine the age at which the population became susceptible to disease in childhood. With appositional growth of bone, the nutrient foramen maintains its original position relative to the center of ossification during growth. By projecting the nutrient canal until it intersects with the center of the medullary cavity, the point from which growth starts can be determined, and hence the growth from each end can be measured. Once a line has been formed, its position within the bone is fixed

and it is possible to place a time of formation on a line. Many populations demonstrated a larger number of lines in that part of the bone associated with infancy (Wells, 1967; Woodall, 1968; Allison et al., 1974; Hatch, 1983; Rathbun, 1987). This tallies with the work of Gindhart (1969) on contemporary children. Other surveys have shown a majority of lines formed during adolescence (Hunt and Hatch, 1981; Maat, 1984; Hummert and Van Gerven, 1985), suggesting that lines had little time to disappear before death, or that there was greater vulnerability during the growth spurt. Hatch (1983), studying adolescent skeletal remains, found that the majority of lines were formed between the ages of 4 and 10, suggesting a pattern of severe childhood illness suffered by the children that eventually led to their death. However, methods for establishing the chronology of transverse lines have varied, from arbitrarily selecting a "typical" length for a bone at birth and then assuming equal yearly increments of growth (Allison et al., 1974; McHenry and Schulz, 1976), to using growth data based on the specific population to be studied (Hummert and Van Gerven, 1985), to the use of contemporary data from American children (Hunt and Hatch, 1981; Maat, 1984). Although the last approach is prone to error due to genetic, environmental, and cultural differences, it reflects empirically determined growth patters rather than postulating hypothetical yearly increments. Comparisons have also been made with other natural markers such as hypoplastic lines in teeth (Wells, 1967; McHenry and Schultz, 1976; Cook, 1979; Cassidy, 1980; Clarke, 1982; Rathbun, 1987), though these are formed by different processes. McHenry and Schultz (1976) found no association between observed hypoplastic lines in teeth without corresponding transverse lines in bone.

In summary, there are two distinct traditions in the Harris-line literature. One is based on studies of living subjects, looking at etiology, formation, and removal of bone markers. The other is based on the examination of lines in archaeological remains and their interpretation. It appears that transverse lines are symmetrically formed around the skeleton, especially at the faster growing ends of long bones, due to a systemic insult that temporarily arrests bone growth. As bone is a dynamic material, lines may disappear with time due to growth and remodeling. Insults could be as diverse as infection, food deprivation, or physical stress, with the resumption of growth in more favorable conditions. Lines are in effect markers of growth recovery.

In paleopathological studies, comparison of lifestyles between populations may be biased or distorted if the samples used are largely juvenile, perhaps the weakest individuals, or predominately elderly, where a longer time had elapsed for line resorption. Another problem with paleopathological studies is that the sites where the skeleton should be sampled to assess line incidence are not clear. Many studies have used only one lower limb bone from each individual, usually the tibia (Wells, 1961, 1967; Garn and Schwager, 1967; Gray, 1967; Garn et al., 1968a,b; Gindhart, 1969; Allison et al., 1974; Cassidy, 1980; Clark, 1981; Clarke, 1982; Hatch, 1983; Maat, 1984; Hummert and van Gerven, 1985; Rathbun, 1987) or the femur (McHenry, 1968), even though published longitudinal studies of contemporary children have used only the distal radius and ulna (Dreizen et al., 1956, 1964; Marshall, 1966; Acheson et al., 1974). The reason cited for the use of the lower limb bones in archaeological material is that the transverse lines are more easily seen in these bones because they grow more rapidly at their ends than do the upper-limb bones (Eliot et al., 1927; Park, 1964; Garn et al., 1968a,b). No two papers agree on the relative frequency with which lines are formed in different bones, raising the issue of sample standardization. Which bone or bones should form the basis of a study? It seems wrong to assume that transverse lines are laid down equally and symmetrically in all bones when lines have been observed to vary in number and intensity in different bones by Dreizen et al. (1956) and Steinbock (1976). These authors appear to have assumed that lines occur symmetrically across the midline, as reported more clearly by Eliot et al. (1927) and Park (1964).

Wood et al. (1992) raise a series of issues involving the interpretation of skeletal markers, as the data alone do not speak for

themselves. Many demographic factors need to be taken into account to ensure an accurate interpretation of any skeletal change. However, there is still a need to unravel the issues concerning transverse (Harris) lines in long bones, placing their relevance more firmly and scientifically as a tool in paleopathology. This work attempts to determine the relevance of these lines in assessing the health status of a population by addressing the issues the symmetry and distribution within the skeleton.

MATERIALS AND METHODS

The material excavated from Waterford City dates from four periods: (1) mid-11th to early 12th century A.D. (Hiberno-Norse); (2) early 12th to mid-13th century A.D. (Viking/Norman transition); (3) mid-13th to 16th century A.D. (medieval); and (4) 17th/18th century settlement. A total of 285 individuals were examined from the excavation and reported elsewhere (Power, 1995), and 58 of these were examined in the present survey. In the earliest period, some individuals were buried in timber-lined graves while some were buried in stone-lined graves. From the second period onward, burial in wooden coffins or shrouds was the norm. Waterford was one of the principal towns in Ireland throughout this period, with links across Saint George's Channel to the neighboring west coast areas of Wales, southwest England, and France. The long time period covered by these remains introduces the possibility of a change in the health of the population due to various demographic factors that could affect the incidence of transverse lines. Such factors might include an increasing local population, an influx of new residents (possibly introducing new illnesses), or more simply a change in diet. However, the diet appears to have remained fairly constant until possibly the last 50 years or so of the period covered by the excavation. It was fairly simple (McCormack, 1995; Tierney, 1995), based on cereals, milk products, root vegetables, and berries, supplemented with variable amounts of meat and fish. Potatoes were not found in the ordinary diet until the end of the 17th century.

The skeletal material excavated between 1982 and 1983 from the Abbey of Tintern Minor in County Wexford consisted of 88 individuals buried during the period ca. 1539 to ca. 1576 A.D., of which 15 were examined in this work. These postmonastic remains were found within the abbey and date to a time prior to residence of the Colclough family. Tintern Abbey was a Cistercian Abbey, named after its counterpart Tintern Major in Gwent in Wales, whence the first monks came ca. 1200 A.D. and stayed until it was suppressed in 1536 A.D. It was converted into living quarters in 1576 when the abbey and lands were handed to the Colclough family. The condition of the skeletal remains varied from those in an excellent state of preservation to those consisting of fragmentary remains. The burial sites were extensively disturbed due to the usage of each cemetery. In addition the Waterford sites suffered damage due to modern construction machinery and waterlogging during the excavation. The individual skeletons selected for study from these two populations were those that had the greatest number of intact (or nearly so) pairs of long bones. Selection was therefore random with respect to the occurrence of Harris lines, favoring the better-preserved remains.

We examined 633 long bones or parts thereof from 73 individuals (Table 1). All bones were radiographed (Kodak Industrex film, exposure of 65 kV, 320 mA for 3.2 sec with a film tube distance of 1.55 m) in the anteroposterior plane with the posterior surface of each bone in contact with the film cassette (Paleopathological Association, 1991). Using the standardized description, a transverse line was counted if it was visible to the naked eye and extended at least a quarter of the way across the diaphysis (Paleopathological Association, 1991). Reproducibility on the radiograph was confirmed as identical line counts were obtained for a sample of bones radiographed on two separate occasions by two different investigators. For this survey, all radiographs were examined on at least two separate occasions by the same observer and the observations were found to be identical. In addition, lines were also further classified as "heavy" or "faint." Each line was located within each bone by taking the following four measurements on

TABLE 1. Distribution of individuals and bones within the sample used in the study

	11–12th century	mid-12–16th century	17–18th century	Tintern	Total
No. adults	16	24	7	12	59
No. juveniles	7	4	0	3	14
No. adult bones	135	221	67	99	522
No. juvenile bones	57	40	0	14	111

the radiograph: (1) maximum length of the bone under examination (greatest length including any processes); (2) distance of line from the proximal or distal end of the bone; (3) the length of the line; and (4) the width of the diaphysis at the point of the line.

The equipment setup ensured that there was no measurable magnification of the specimens. The individuals were classified as adult or juvenile according to the presence or absence of the femoral epiphysis. Juveniles were further subdivided into age groups 0–13 years, 13–16 years, 16–20 years, and 20–23 years, according to the degree of epiphyseal union in the various long bones (Brothwell, 1981). Adult bones were aged by studying changes in radiolucency in the trabecular structure and density revealed on radiographs of the proximal ends of each long bone (Lynnerup et al., 1990).

The age of formation of each line was calculated using a method similar to that used by Maresh (1943, 1955) and Maat (1984). As the rate of growth of the proximal and distal ends of each bone differed, the calculated diaphyseal lengths were divided using the proportions given by Digby (1916) to give the amount of growth at each end. Finally the calculated proximal and distal diaphyseal lengths were expressed as percentages of the adult diaphyseal length. The length of each line was also expressed as a ratio of the total width of the bone at that point. All results were analyzed using the Wilcoxon Signed-Rank test and the group comparison t-test with a significance level of 0.05.

RESULTS

Macroscopic findings

Paleopathological findings from Waterford include osteomata, rickets, cribra orbitalia, periosteal lesions, degenerative joint disease, exostoses, osteochondritis dissecans, and fractures (including one fatal weapon injury). Anatomical variations and various dental pathologies (including hypoplasias, abscesses, periodontal disease, attrition, and antemortem tooth loss) were also evident. At Tintern the findings were similar except for the absence of rickets. Detailed analysis of the remains from the Waterford site has been presented elsewhere (Power, 1995). Forty individuals from Waterford from the medieval period suffered from nonspecific infections of unknown etiology, in the form of inflammatory and reactive lesions including periostitis and osteitis, unrelated to a primary traumatic event. Most individuals from this site (83%) had periosteal lesions, which were bilateral in 57% of cases, with long bone involvement. The tibiae had the highest prevalence of these lesions (23% of right and 19.5% of left adult tibiae). These lesions may have been due to vitamin C deficiency, which is additionally suggested in the Waterford material by high levels of premortem tooth loss, resorption of alveolar bone, and treponemal disease. In adult remains with fully erupted dentition and infectious lesions, 65% had some alveolar recession and/or antemortem tooth loss, while 30% had antemortem tooth loss alone. Sixteen percent of individuals also suffered from porotic lesions on the skull. Of the skeletons selected for this study, eight had antemortem tooth loss, 11 had alveolar resorption, and only five had periosteal lesions. Twenty subjects had had periods of stress as indicated by enamel hypoplasias, and two had rickets. At Tintern, only four individuals showed periosteal lesions unrelated to trauma, two of which occurred on lower limb bones that were not included in this study. In the remains used, alveolar recession occurred in 11 individuals and six had antemortem tooth loss, whilst enamel hypoplasias occurred in three of the individuals.

Cribra orbitalia occurred in 12 individuals from Waterford and was present in four of the individuals used in this study, all from the three earliest periods. In addition, porous lesions of the skull vault also occurred in two individuals from the Viking/Norman transition period and one in the 17th/18th century periods. In only one individual were porotic skull lesions and periosteal lesions seen together. Of the Tintern remains, 12 had cribra orbitalia though only one of these was included in this survey.

Lines in intact bones

At least one transverse line was seen in 35% of all intact bones, and because of the relatively small number of bones from each burial group, all were pooled. When these were subdivided by age, juvenile long bones were more likely to demonstrate at least one line than adult bones. The presence of a line seen on a radiograph was confirmed visually by longitudinally sectioning a representative sample of 20 long bones (Fig. 1). Lines were seen to stand out as transversely orientated denser trabeculae within an apparently random matrix of trabeculae. In the femur and tibia they were usually found on the medial side of the bone only. Nearer to the midpoint of the shaft, lines were easier to identify. Straight transverse lines were seen in all long bones except the humerus, where thick continuous curved lines were visible in the distal ends of the bone, and when sectioned each line was seen to consist of several finer lines unlike transverse lines elsewhere. The frequency of occurrence varied with the type of bone (Fig. 2), but the distribution did not vary between the different age groupings. Individual adult bones were more likely to demonstrate at least one line than juvenile bones, except for a slightly higher incidence in the juvenile femur and fibula. Lines were seen most frequently in the tibia (79%). Normally lines, whether heavy or faint, extended across three-quarters of the shaft. However, a greater number of heavy lines extended across a greater proportion of the bone width than did the faint lines. Distally faint lines were most common, further from the primary center of ossification than the heavy lines.

Lines in proximal/distal bone segments

The sample was increased by dividing the sample into proximal and distal segments to include the broken bones (Fig. 3). The distal tibia demonstrated the highest frequency of lines (84%), followed by the proximal tibia. No lines were seen in the proximal end of the femur. A total of 1,265 lines were counted in the sample. Of these, faint lines were the more numerous. Across the whole population of bones, the tibia averaged 6.3 lines (Fig. 4a). In each tibia that had a line to be counted, there was an average of 10 lines, almost equally divided between proximal and distal regions (Fig. 4b). Faint lines were four times more common than heavy lines in the distal tibia (Fig. 5). In the radius, there were proportionately more faint lines and fewer heavy lines than in the femur and the fibula. No heavy lines were observed in the ulna. Lines of both types were more numerous in the juvenile than adult bones, except in the tibia, where the reverse was true. In the juvenile population, lines were more numerous in the femur (3.92 per bone) than the tibia (3.75), though the fibula demonstrated more heavy lines than either.

Symmetry of lines

Using the full sample of bones, subdivided into right and left, the average number of lines per region of each bone was equal or slightly greater on the left than on the right for both heavy and faint lines. The differences were not statistically significant, though in the juvenile tibiae and fibulae the right side demonstrated more heavy lines. To allow comparison of the number of lines between bones from the right and left sides, only pairs of intact bones were used. This resulted in 128 pairs of adult and 34 pairs of juvenile bones for analysis, of which 92 pairs demonstrated no lines. In the pairs with lines there were more left bones with at least one line than right bones, and the average number of lines in a bone was greater on the left than for the corresponding bone on the right (Fig. 6). Within this population of pairs, no significant difference was found between the total number of lines in a right bone of a pair compared to that in a left bone, implying symmetry in the inci-

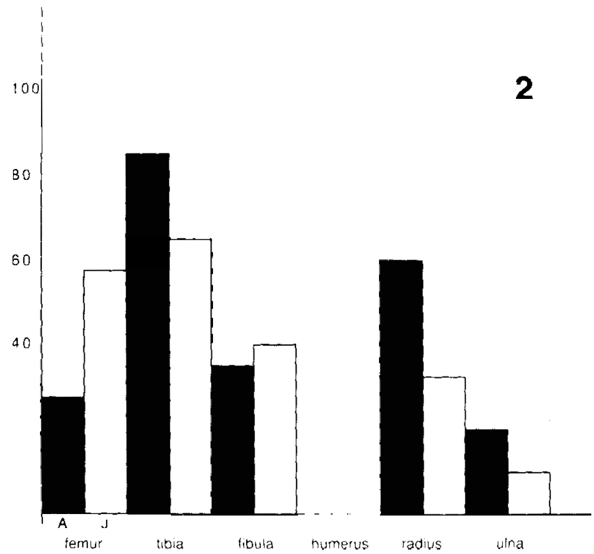


Fig. 2. Percentage of intact adult and juvenile bones with at least one line per total number of bones of that type.

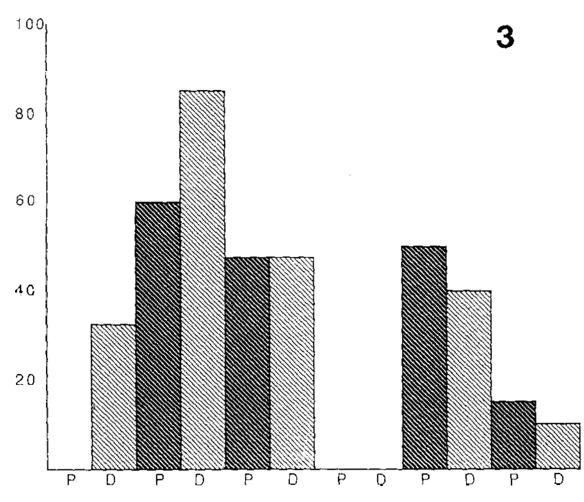
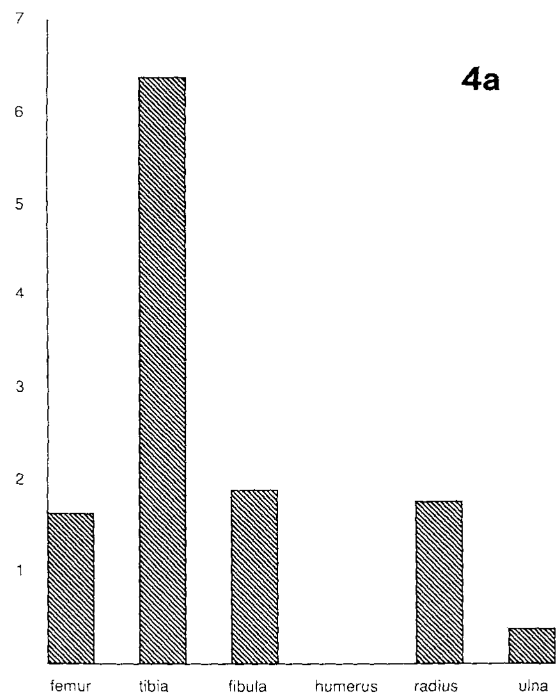


Fig. 3. Percentage of proximal and distal parts of bone with at least one line.

dence of lines within a population (Wilcoxon Signed-Rank test). However, when this population was divided into two subgroups, 13 pairs of bones with exactly the same number of lines on the right and left, and 57 pairs of bones without an equal numbers of lines in each, there were a significant number of pairs of bones that had a difference in the number of lines ($P = 0.05$). It therefore cannot be readily assumed that the incidence of lines is symmetrical within an individual skeleton.

Only intact left bones were used to investigate the symmetry of the number of lines between proximal and distal segments of a bone and between the different long bones.



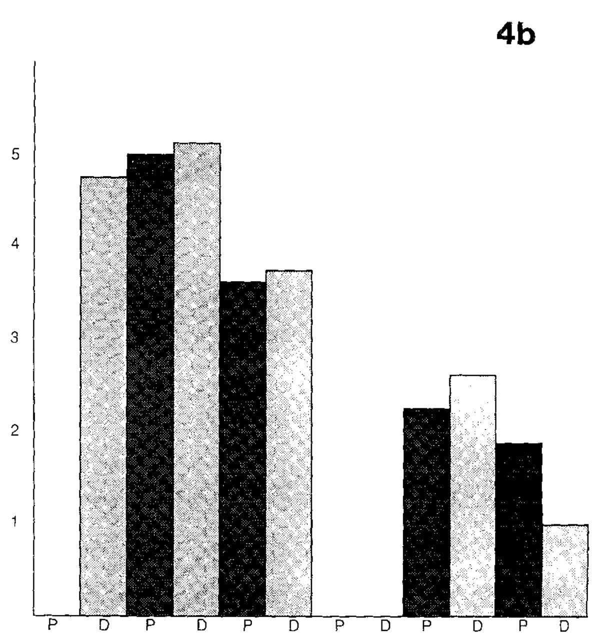


Fig. 4. **a:** Average number of transverse lines per bone. **b:** Average number of lines per part of bone in those which have lines.

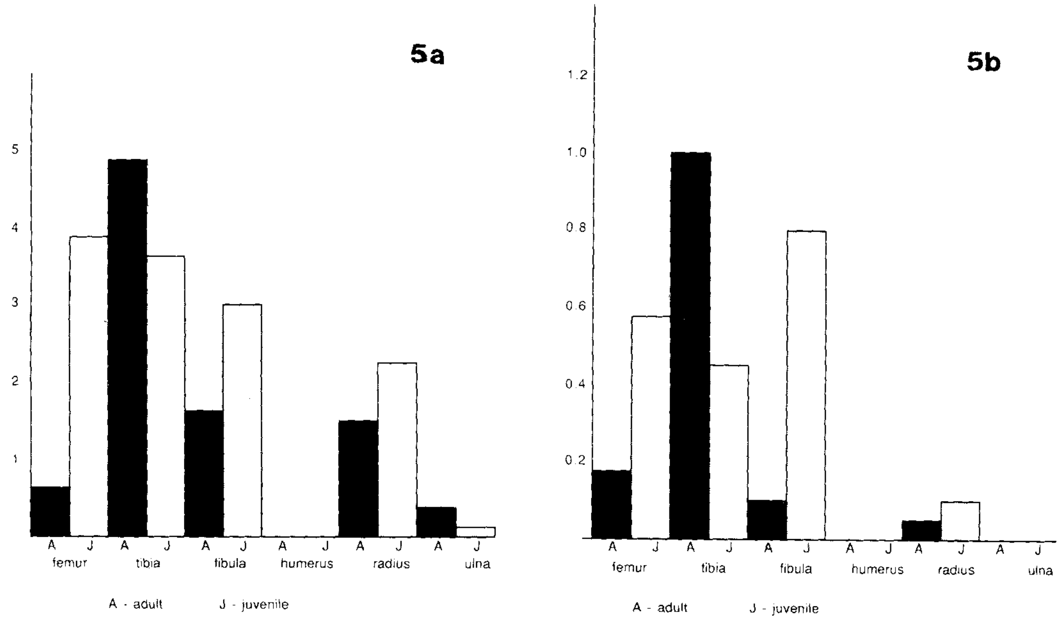


Fig. 5. Average number of lines per bone according to the density of the lines. **a:** Faint lines. **b:** Heavy lines.

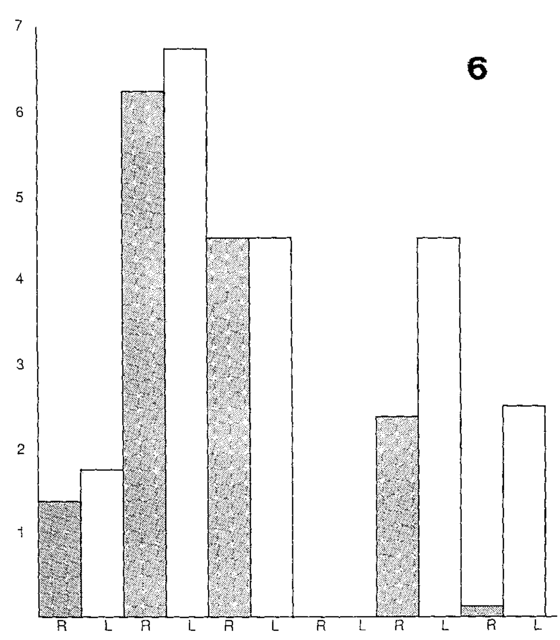


Fig. 6. Average number of lines per paired bone.

Overall, within the same bone, there was no difference between the number of lines in the proximal and distal segments. There was, however, a significant difference ($P < 0.05$) in the femora of the 11th–12th and 12th–16th century and the tibiae in the 11–12th century. In addition, there was a significant difference between the number of lines between the bone types, e.g., proximal femur vs. distal tibia ($P < 0.05$).

Age of formation of lines

Lines were seen to be formed at all ages from as early as the first 2 months of extrauterine life until the end of bone growth. Irrespective of whether lines were faint or heavy, proximal or distal, the largest number of lines were formed at the age of 10–11 years (Fig. 7). There were relatively few lines present that were formed before the age of 5 years, and these were mostly seen in the distal femur and tibia and proximal radius. The pattern of age of formation varied within the bone; for example, the majority of lines in the tibia were formed in the distal end up to 13 years and thereafter a greater number were formed in the proximal end of the bone. This was also seen in the fibula, though the crucial age here was 11 years. In the radius the pattern was reversed, with the early lines in the proximal end and the later lines in the distal end.

The age at death was determined for all adult individuals from the radiographs of the femoral neck, and the largest group were aged between 50 and 60 years. No individuals were placed in the 16–20 and 70+ year groups. To allow comparison, individuals were grouped into the three broad bands of 0–24, 25–50, and 50+ years. The largest proportion of intact bones with at least one line was found in the 25–50 year age band (Fig. 8). This remained so when the broken bones were included to increase the sample size. The older individuals possessed fewer bones with lines than the two younger age groups. This trend was seen across most bone types except the femur and fibula, where the greatest proportion was seen in the youngest age group. In those bones that did possess lines, both heavy and faint, the average number of lines was greater in the 0–24 year age group than in the older age groups (Fig. 9). This trend was seen in most types of bone. However, few lines of either type were seen in the ulnae of the 0–24 year age group. The 25–50 year age group exhibited few heavy lines in the femora and a greater proportion of heavy lines in the tibiae. The trends seen throughout the whole population were also seen when the bones were analyzed in a similar manner but divided according to burial period.

DISCUSSION

The aim of this paper was to look at the incidence and symmetry of transverse (Harris) lines within a population of archaeological remains. Results clearly indicate that the average number of lines in the right and left bones were different, within burial groups, within each bone type, and within each individual. This difference in number, usually only two or three lines, was not statistically significant when the population was viewed as a whole. However, analyzing the differences between those pairs of bones that demonstrated equal numbers of lines and those that did not, there was a significantly large number of pairs that did not possess equal numbers of lines. In essence, while there was no significant difference between the total number of lines in the right and left bones, there was a significant difference between the number of pairs with an equal and unequal number of lines. Therefore, while the health status of a large population could be determined using bones taken from only one side of the body, it would not be the case with small populations or individuals, as those on the other side, although in general agreement, were not identical. In the latter, erroneous interpretations could be made depending on whether the bone selected came from the side with the greater or lesser number of lines.

Location of lines

It was noted, especially in the forearm bones, that lines were more numerous on the left side of the individual. Such a finding was suggestive of a dominant right side as lines disappeared at a greater rate by resorption and apposition on the dominant side, though this would seem to contradict the proposal that lines were more prominent due

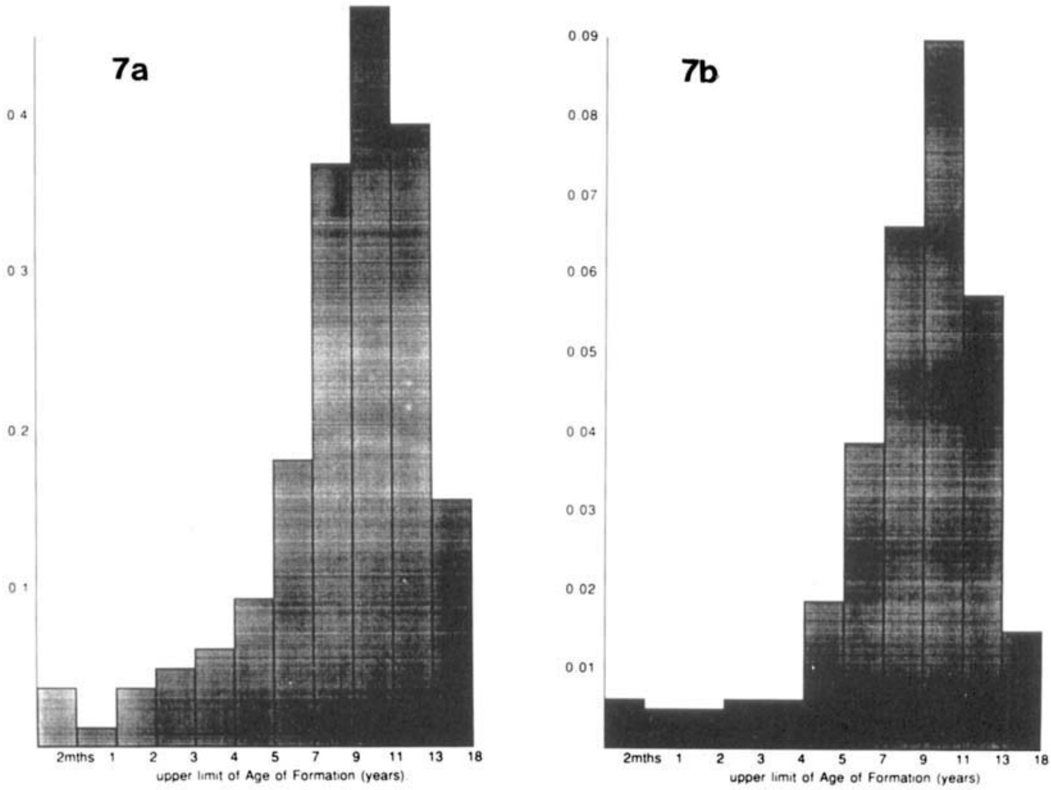


Fig. 7. Average number of lines in the whole sample according to age of line formation. **a:** Faint lines. **b:** Heavy lines.

to the greater physical stress suffered by a bone (Harris, 1933). There were significant differences between the numbers of lines present in the proximal and distal ends of each bone type, which indicates that a single long bone could not be taken as representative of all bones in the body of an individual, as assumed in previous studies (Wells, 1961, 1967; Allison et al., 1974; Garn and Schwager, 1967; Gray, 1967; Garn et al., 1968a,b; McHenry, 1968; Gindhart, 1969; Cassidy, 1980; Clarke, 1982; Hatch, 1983; Maat, 1984; Hummert and Van Gerven, 1985; Rathbun, 1987). There was no relationship between the numbers of lines demonstrated in each type of bone. Therefore, if only one bone could be used in a survey then the tibia would provide the greatest chance of demonstrating a line. However, it was also observed that lines occurred within an individual's other bones without a corresponding line in the tibia. In addition, there are conflicting reports of the incidence of transverse lines within each bone type (Eliot et al., 1927; Park, 1964; Garn et al., 1968a,b) which differ from the results obtained in the present study. In essence, from this survey the incidence of lines was higher in bones of the lower limb, being more likely at the faster-growing ends of the bone. It has been proposed that the superior circulatory conditions and the predominance of osteoblasts in these regions of faster growth facilitate line formation (Park, 1964). However, this does not explain the high incidence of lines reported in the slower-growing distal ends of the tibia and fibula (Garn et al., 1968b). Perhaps osteoblastic activity decreased without a decrease in cartilage growth and then returned on recovery with a sudden spurt. The faster-growing ends may have produced enough cartilage for the osteoblastic spurt, while the slow-growing ends had less cartilage laid down, so that when the

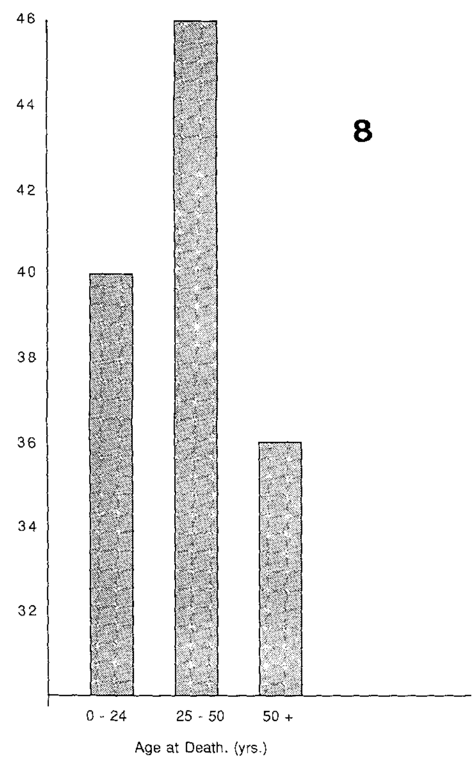


Fig. 8. Percentage of bones with at least one line according to age at death.

osteoblastic spurt occurred a line was more likely to form (Park, 1964). Throughout life, and especially by old age, remodeling would have occurred with a resultant decrease in the incidence of lines (Garn and Schwager, 1967). The present results support this view. Therefore, in a study of health conditions in an archaeological population, if the original premise of the lines' being a permanent health marker is accepted, more than one bone type and all long bones, if possible, should be used.

In the narrower bones, the lines existed primarly in the middle two-thirds of the width of the bone, possibly due to bone resorption from without. However, in the tibia and femur, the current results clearly demonstrated lines on the medial aspect of the bone, consistent with differential remodeling and cortical drift (Garn et al., 1968b). While resorption occurred on both sides, appositional growth occurred to a greater extent on the lateral edge. Thus, greater new bone formation laterally caused the line to move away from the lateral edge.

Where the epiphysis was relatively straight and perpendicular to the shaft of the bone, transverse lines were straight and perpendicular to the shaft and easily detected on an anteroposterior radiograph. However, where there were multiple epiphyses, as in the proximal femur and humerus, the lines may not be as easily detected due to their angulation to the shaft.

Heavy and numerous curved lines were found in every distal humerus, though they were thought not to be true transverse lines, since this is the slower-growing end of the bone, where they would not have been expected to form. Other workers (Eliot et al., 1927; Park, 1964; Garn et al., 1968b) found few lines in the distal humerus. This supports the idea that the numerous lines found at this location in this study were not transverse lines. Their curved architecture suggests that they are part of the normal internal bone structure.

Maat (1984) defined three types of lines according to density, reasoning that heavy lines were produced by more serious attacks of disease. The results of the present study, which distinguished two types, heavy and faint, indicate that both followed a similar pattern of occurrence, with the exception of the radius, which demonstrated fewer heavy lines than the femur and fibula, but greater numbers of faint lines. It had been expected that if a heavy line was due to a serious disease, then the disease would have been more likely to affect all bones. The results did not support this hypothesis, as the tibia demonstrated more heavy lines than any other bone. In addition, some individuals exhibited heavy lines within one bone but no lines in any other long bone. It could be suggested that in these many heavy lines may have been reduced to faint lines, or totally removed due to bone remodeling. However, heavy lines were more likely to be longer than faint lines, suggesting they were more resistant to remodeling than faint lines.

Age at formation of lines

Longitudinal surveys of children have suggested that larger numbers of lines form during early childhood, consistent with most

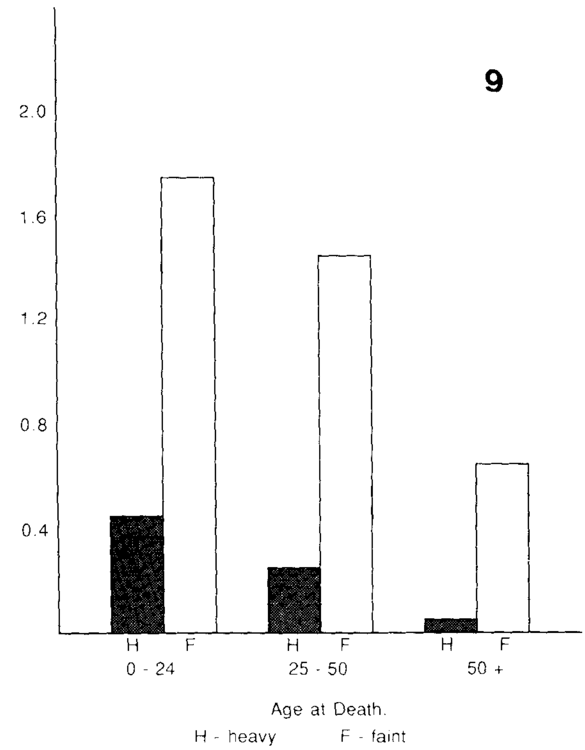


Fig. 9. Average number of lines per bone according to age at death.

early childhood illness (Garn et al., 1968a,b; Gindhart, 1969; Hewitt et al., 1955). Yet in the present survey, the majority of lines appeared to have formed when each individual was around the age of 10–11 years, with few lines remaining from early childhood or formed in late adolescence. In the adult skeletons, few lines represented either the early years of formation or the late teenage years. Why do archaeological surveys consistently demonstrate a predominance of lines formed in later childhood when longitudinal surveys indicate that lines are also formed in early childhood and then disappear after a few years (Harris, 1931a,b; Garn et al., 1968b)? A line formed at the epiphyseal plate would, during growth, remain in its original position, now part of the diaphysis. In addition, the bone would be constantly remodeled by resorption from within; and appositional growth, and thus remodeling with an increase in mineralization, would result in the disappearance of a line. This could explain the lack of early lines in the present survey, with the lines that did persist being more resistant to remodeling and indicative of a more serious "illness" or "stress." Following this argument, it would not be surprising that lines formed later during growth persisted longer into adult life. In juvenile bones, the majority of lines were present at the ends of the diaphysis, supporting the remodeling theory. Therefore, lines in adults would not necessarily reflect all illnesses or stresses during life, but only the more recent episodes.

Previous workers who reported large numbers of lines formed in the early teens attributed their formation to stress during the growth spurt (Hunt and Hatch, 1981; Maat, 1984; Hummert and Van Gerven, 1985). The high frequency of lines formed between the ages of 10 and 11 years in this survey may also correspond to the beginning of the growth spurt, and the lack of lines formed in the late teens would suggest that this was a relatively healthy time of life for most of the adult individuals in the survey. It was

surprising, though, to find that younger adults possessed a larger proportion of bones *with* lines and *containing* a larger number of lines than were found in the juveniles. However, in the 12th–16th century and Tintern burial groups, the juveniles demonstrated a higher proportion of bones with lines. The lack of lines seen in the juvenile bones of the 11th–12th century could indicate a period of relatively good health. Alternatively, the longer burial time could have made lines more difficult to detect, as bones from this period were not in as good a condition as the rest of the survey sample. The juvenile femur and fibula were more likely to possess a larger number of lines than their adult counterparts. The epiphyses of these two bones, the last to fuse, allow growth to occur after all other bones had reached their adult form. Remodeling may therefore have occurred at a slower rate in these bones, as growth took longer, accounting for the larger proportion of juvenile to adult lines in the femur and fibula when compared to the other bones.

To use transverse lines as an indicator of "stress" in a population assumes that once a line is formed it remains in the bone as evidence of that "stress"; but this cannot be the case when bones are constantly remodeled. On the basis of the results reported here and the assumption that they are permanent, two different "health" findings would be valid. If a population consisted of elderly individuals, with fewer lines detected, a relatively healthy population would be suggested. On the other hand, if only younger individuals from the same population were studied with a larger number of lines detected, the health status of the population would be assumed to be different. We suggest that the incidence of transverse (Harris) lines in adult populations warrants conclusions only about the health of the individual between the age of 10 and 20 years. For an analysis of health during the younger childhood years, juvenile bones would be needed in which there would have been less remodeling. However, problems may arise here if an individual died before bone maturity was reached; such bones would not be representative of the whole population as they might reflect an atypically sickly or weak individual.

In conclusion, it could be said that transverse lines may indicate that a period of stress or disease had occurred, but the lack of a transverse line could *not* be interpreted as a lack of disease. Furthermore, as transverse lines are essentially lines of *recovery* of growth, it has been suggested that the most prominent lines are produced by the most vigorous recovery and are actually found in the healthiest specimens (Park, 1964; Ozonoff, 1988; Wood et al., 1992). Care must be taken in the interpretation of transverse lines in archaeological specimens, especially if only a single bone is examined, considering the lack of symmetry. Transverse lines are but one of the factors that could be used to indicate the health of a population, and no one health indicator should be used in isolation.

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